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Simulation and Measurement of an Electrostatic Discharge

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ABSTRACT

Electrostatic discharge is the sudden and brief electric current that flashes between two objects at different voltages. This is a serious issue ranging in application from solid-state electronics to spectacular and dangerous lightning strikes (arc flashes). The research herein presents work on the experimental simulation and measurement of the energy in an electrostatic discharge. The energy released in these discharges has been linked to ignitions and burning in a number of documented disasters and can be enormously hazardous in many other industrial scenarios. Simulations of electrostatic discharges were designed to specifications by IEC standards. This is typically based on the residual voltage/charge on the discharge capacitor, whereas this research examines the voltage and current in the actual spark in order to obtain a more precise comparative measurement of the energy dissipated.

Introduction

Electrostatic discharges have been identified as one of the most likely cause in a number of incidents of fire and explosions with unexplained ignitions [1-3]. The lack of data and suitable models forms a void in the analysis to quantify the significances of static electricity in these situations. Emphasis must be place on the fact that electrostatic charge build up is a natural physics phenomenon that will occur with any situation of charge transfer. It is not limited to human interactions with our physical world. In Industrial scenarios, where repetitive actions cause a build up by repetitive transfer of minuscule amount of charge, creates a significant hazard based on the possible catastrophic damage that can destroy plant and personnel.

Simulations of electrostatic discharges were designed to specifications by IEC standards[4]. This is typically based on the residual voltage/charge on the discharge capacitor, whereas this research examines the voltage and current in the actual spark in order to obtain a more precise comparative measurement of the energy dissipated. This allows us to better understand the energies in the discharge.

In the cases of Barton Solvent and Hayes Lemmerz International electrostatic discharge was considered to be the possible source ignition, but it was deemed unlikely as spark energy was too low for ignition in Hayes' case[5, 6],. The Barton Solvent facility in Kansas was involved in an explosion and fire originating in a vertical aboveground storage tank. Poor design of the tank level float lead to possible accumulations of charges which sparked over at links of the float, leading to an explosion and fire to a large portion of the facility.

Electrostatic discharge as the source of ignition at the incident of Hayes Lemmerz Internal in Indiana was concluded to be too low energy to have ignited an aluminium dust explosion[6]. Fine aluminium dust was being collected in the facility's dust collector which uses a jet to pulse every 90 seconds to move the dusts, inadvertently creating a dust cloud of sufficient concentration for dust explosion. However it was assumed electrostatic build up would not provide sufficient energy to ignite the dust cloud.

The standard, *NFPA77: Recommended Practice on Static Electricity* is a comprehensive guide to the safety practices for prevention of hazards on static electricity[7]. It provides detail information on key issues on bonding/grounding, expands on the tools used to determine hazardous in liquid transfers, and provides advice on prevention in specific conditions. It also presents the commonly used method for energy calculation of ignition,,

$$W = \frac{1}{2}CV^2, V = \frac{1}{C}\int Idt \,, \qquad \text{Equation 1}$$

This is the main issue in this research. This method of energy calculation assumes that there is no residual charge in the capacitor, the energy dissipation in the resistance is minimal and that energy dissipation in the impedance of the discharge circuit will negligible.

The importance of ignition energy consideration is apparent in Oda's paper [8] on Minimum Ignition Energy of Hydrogen Air Mixture. This was an important aspect of the research as hydrogen requires only a hundredth of the minimum ignition energy of hydrocarbons. It was concluded by Oda that the residual energy in the capacitor was insignificant to the overall energy and that it can be taken into account when computing the overall energy. This can also be done for the discharge resistance, so that the energy equation becomes,

$$E_s = E_c - E_r - E_{residual}, \qquad \text{Equation 1}$$

where E_c is the energy in the discharge capacitor, E_r is the energy dissipated in the discharge resistance, and $E_{residual}$ is the capacitor residual energy.

Method

By taking measurements prior and after the discharge point, the voltage drop and current of the discharge can be recorded. This measurement of VI characteristic of the discharge can be used to calculate the energy of the discharge and relate the energy to energy in the capacitor.

A low voltage experiment designed to simulate the discharge was completed to provide preliminary data on energy calculation. The experiment used a standard 30VDC power supply, charging a discharge circuit through a 560KΩ resister as show in Figure 1.

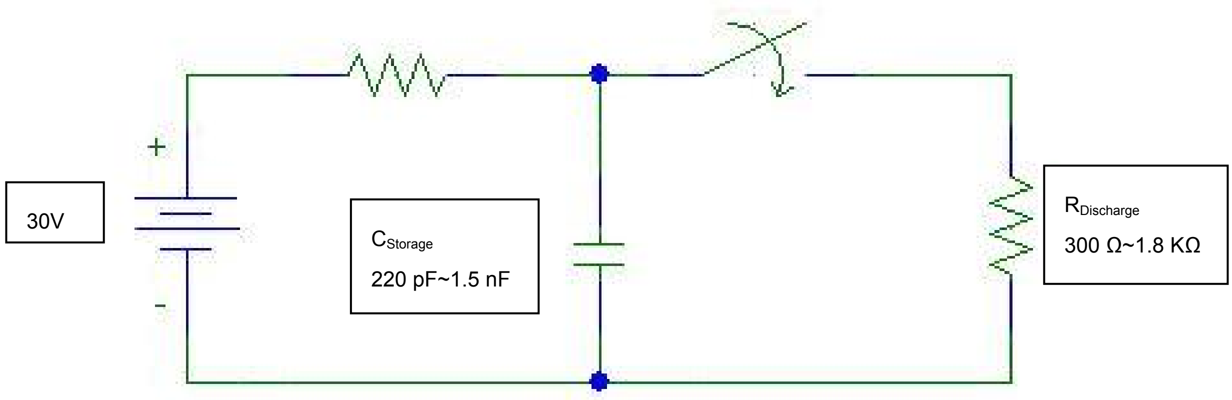

Figure 1. Schematic of the low voltage experimental setup

The capacitors ranged from 220pF to 1.5nF and the resister from 330Ω to 1.8KΩ, values used each set of test are listed in Table 1.

Due to the low voltage, a spark over would not be possible and a switch was used to simulate spark discharge. The discharge is measured by 100X voltage probes at the switch to give a VI characteristic of the discharge.

Results and Discussion

Preliminary results from low voltage experiment are taken by the differential voltage measurements of the discharge. Voltage readings over the discharge period is recorded at, prior to discharge point and after. An example of measurement is presented in Figure 2. As a spark over discharge was not possible, the switch voltage drop was measured. Measurement was taken across the storage capacitor and the discharge resistor; as the ground is common, the voltage drop across the switch is obtain by Vc-Vr. Capacitor energy is given by,

$$W = \frac{1}{2}CV^2, \qquad \text{Equation 3}$$

and the energy dissipated in the discharge resistor is calculated by,

$$W = \int \frac{V^2}{R} dt \,. \qquad \text{Equation 4}$$

From Figure 3, energy in the capacitor is consistent in relation to the size and voltage of the experiment. Figure 4 show the energy dissipation of the discharge resistors, which decrease in magnitude as energy in the storage capacitor decreases. Energy dissipated in the discharge is calculated from the two measured voltages V1 and V2, and found by,

$$W = \int (V_1 - V_2) \times \frac{V_2}{Rdischarge} dt \,, \qquad \text{Equation 5}$$

Results shows that the energy dissipated in the discharge by the switch decrease in relation to the energy in storage capacitor as in Figure 5, but rises in relation to the peak current. The peak current, Figure 6, increase as the resistor value decreases; this increase of energy dissipation in the switch is more apparent than in discharge resistor. Figure 7 and 8 are the voltage and current waveform of the discharge.

From the results, the characteristics of the connections impacted on the data collected. No perfect discharges were recorded, where all energy was accounted for. If total energy present in the discharge circuit is in the storage capacitor then the total energy dissipated in the switch and discharge resistor should equal the capacitor energy. Figure 9, shows the percentage energy that is lost to the impedance of the connections in the circuit in relation to the total energy in the storage capacitor.

Results from low voltage data will assist in measurement and calculation of energy is spark discharge of high voltage experiment. The experiment setup is powered by a 30kV Ultravolt HV power supply, and is shown in Fig. 10. The storage capacitor is charge through a high voltage resistor of 1GΩ, to prevent effects of continual charging while discharging. The storage capacitor is chosen from values of 100pF to 470pF, as to simulate in accordance to HBM[4]. The spark gap is located between the storage capacitor and discharge resistor. Measurement is across the spark gap, with Voltage Divider Bridge of ratio 10,000 to 1. The voltage divider uses a 1GΩ resistor in series with an 110KΩ resistor, as shown in Fig. 11; this limits the effects of measurement on the discharge.

Experimentation with the high voltage and the system described able will provide a clearer understanding of the discharge voltage/current characteristics and net energy dissipated in the discharge. Furthermore, the effects of a higher peak current on the energy dissipation of other components and losses will be shown.

Conclusion

Capacitor energy calculation cannot wholly account for the energy dissipation in an electrostatic discharge. The discharge point differential measurement must be taken in order to characterise the voltage current relationship of the discharge and to calculate the energy dissipation.

Figures and Tables

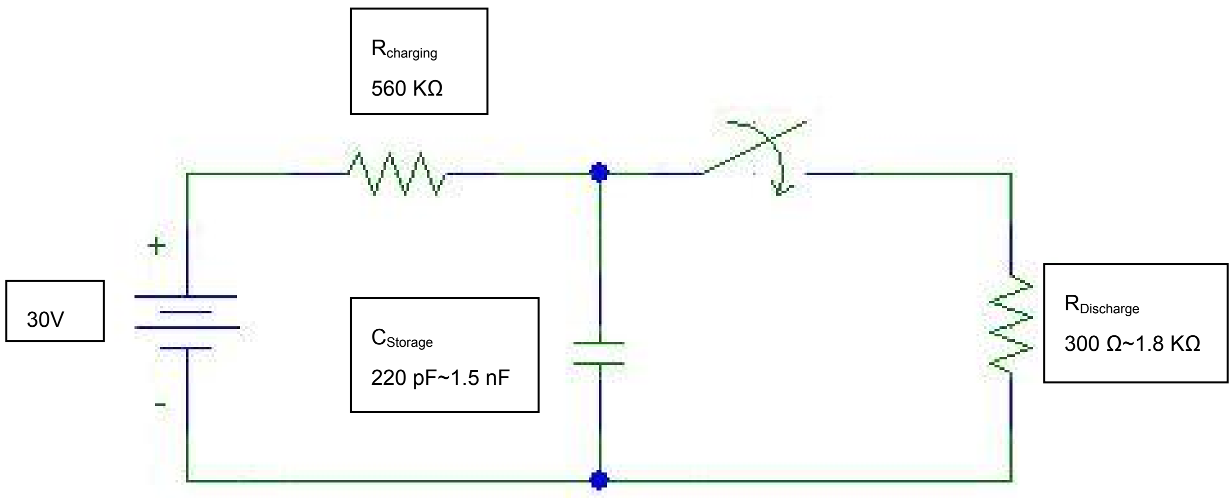

Figure 1. Schematic of the low voltage experimental setup

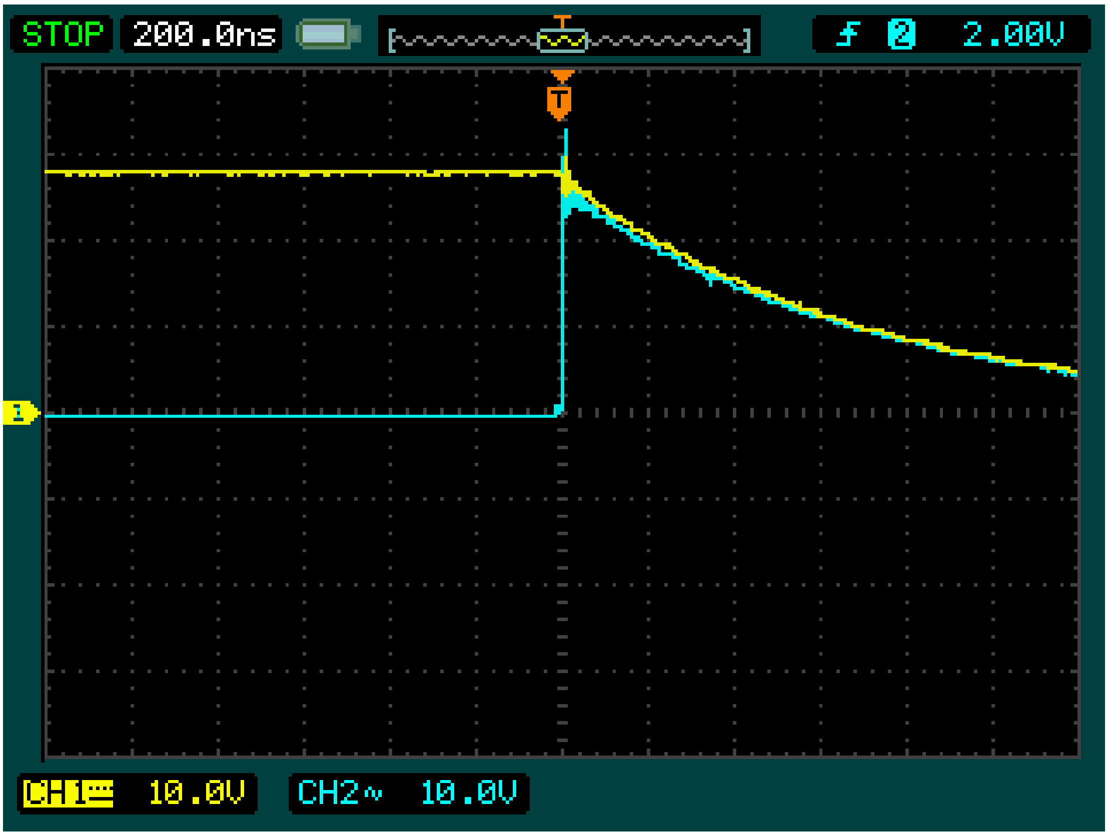

Figure 2.An example of recorded waveform of discharge, where Ch1 is the voltage across the capacitor in yellow, and Ch2 is the voltage across the resistor in blue

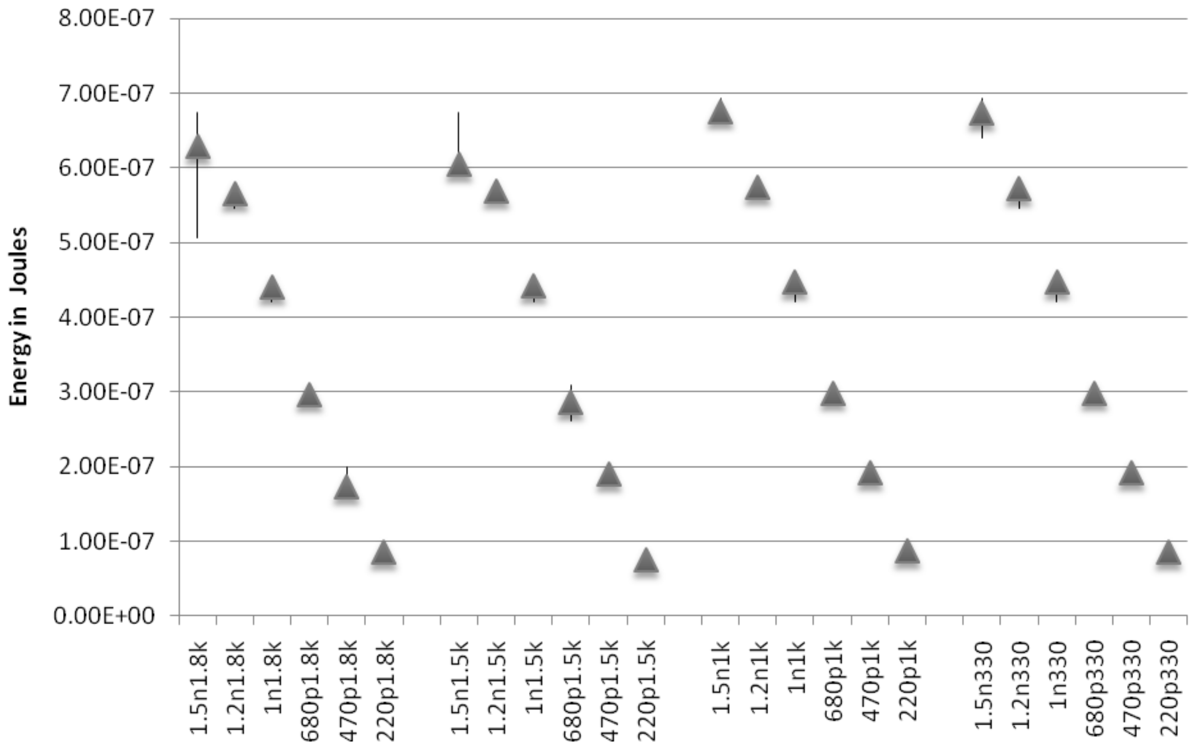

Figure 3. Plot of comparative results showing the energy(J) in the storage capacitor.

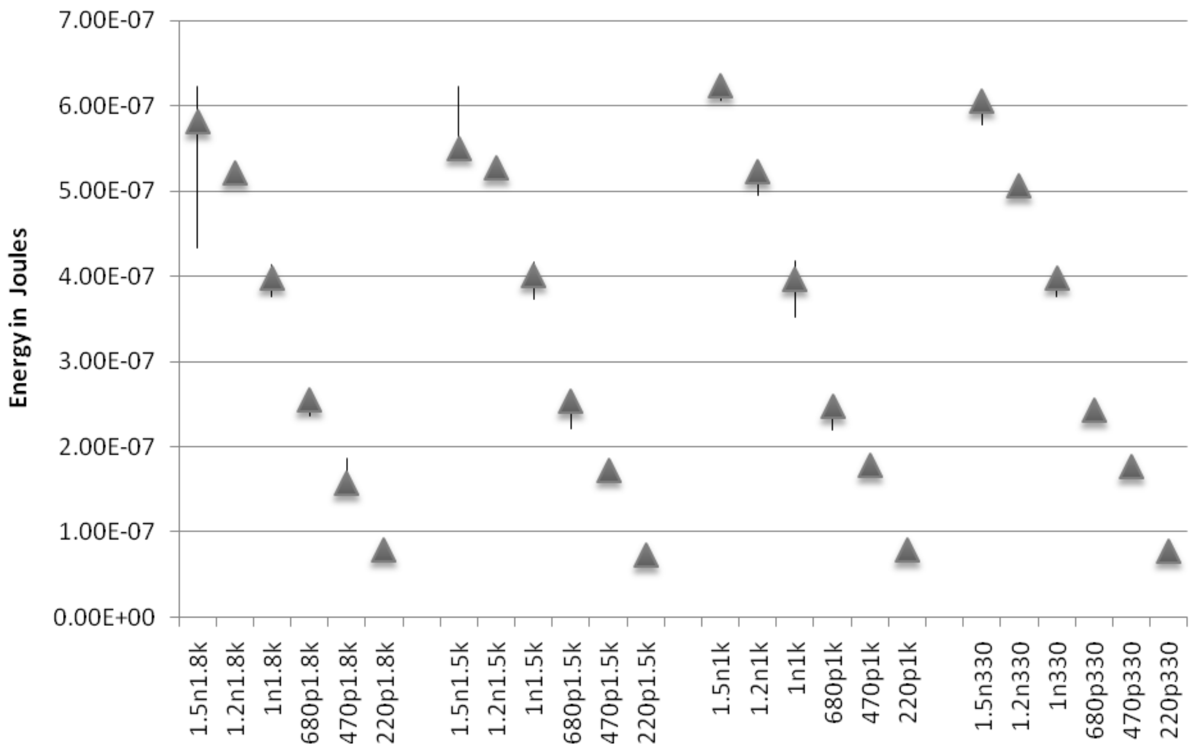

Figure 4. Plot of comparative results showing the energy (J) dissipation in the discharge resistor.

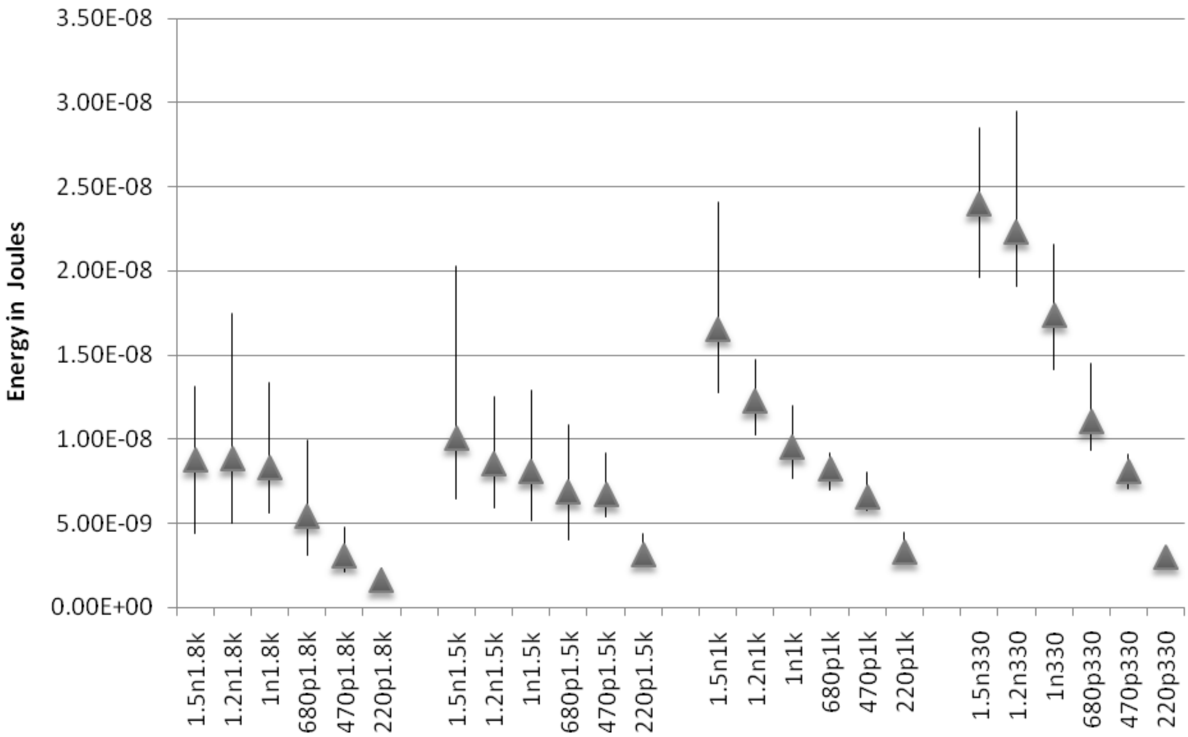

Figure 5. Plot of comparative results showing the energy(J) dissipation in the discharge via the switch.

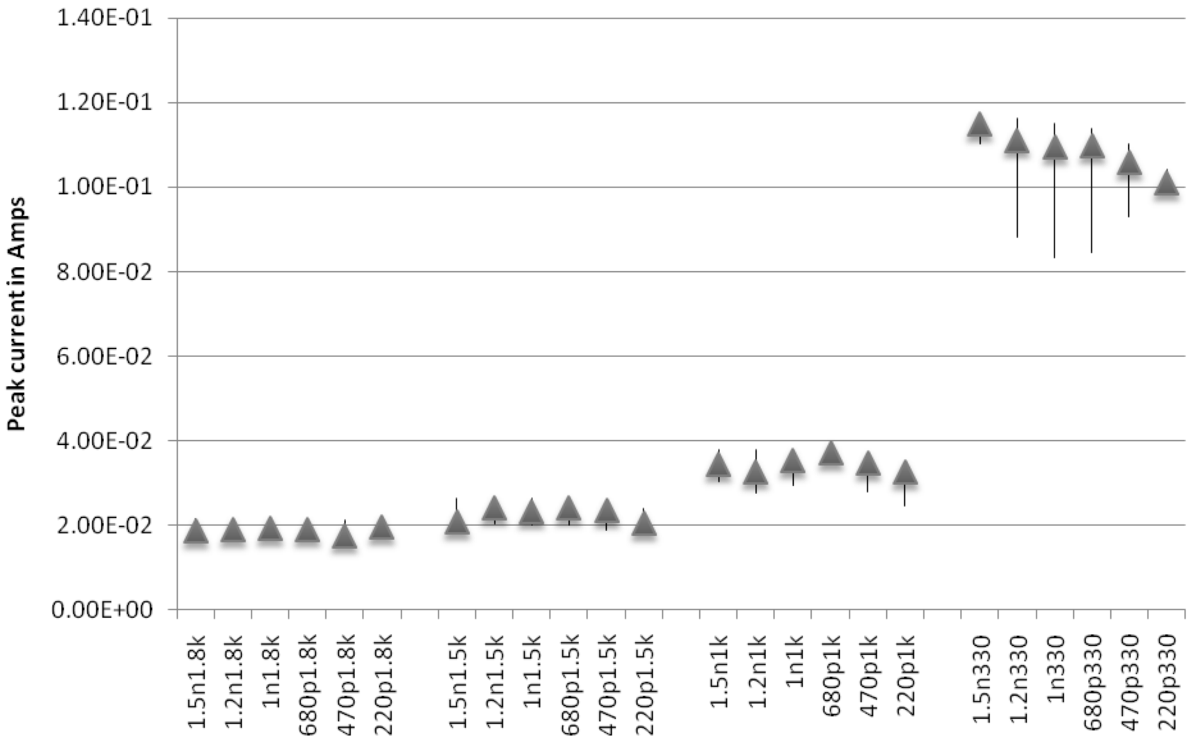

Figure 6. Plot of compartive results showing peak current(Amps) recorded in the discharge

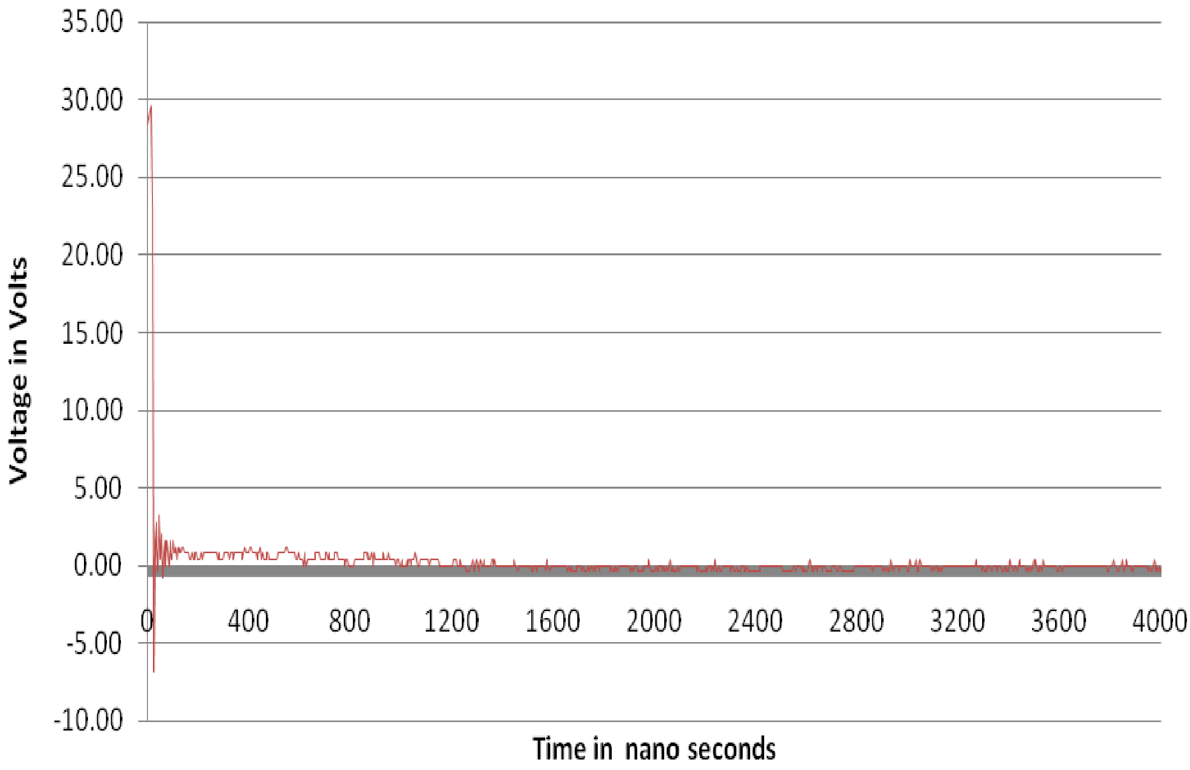

Figure 7. Plot of voltage of the discharge over discharge period.

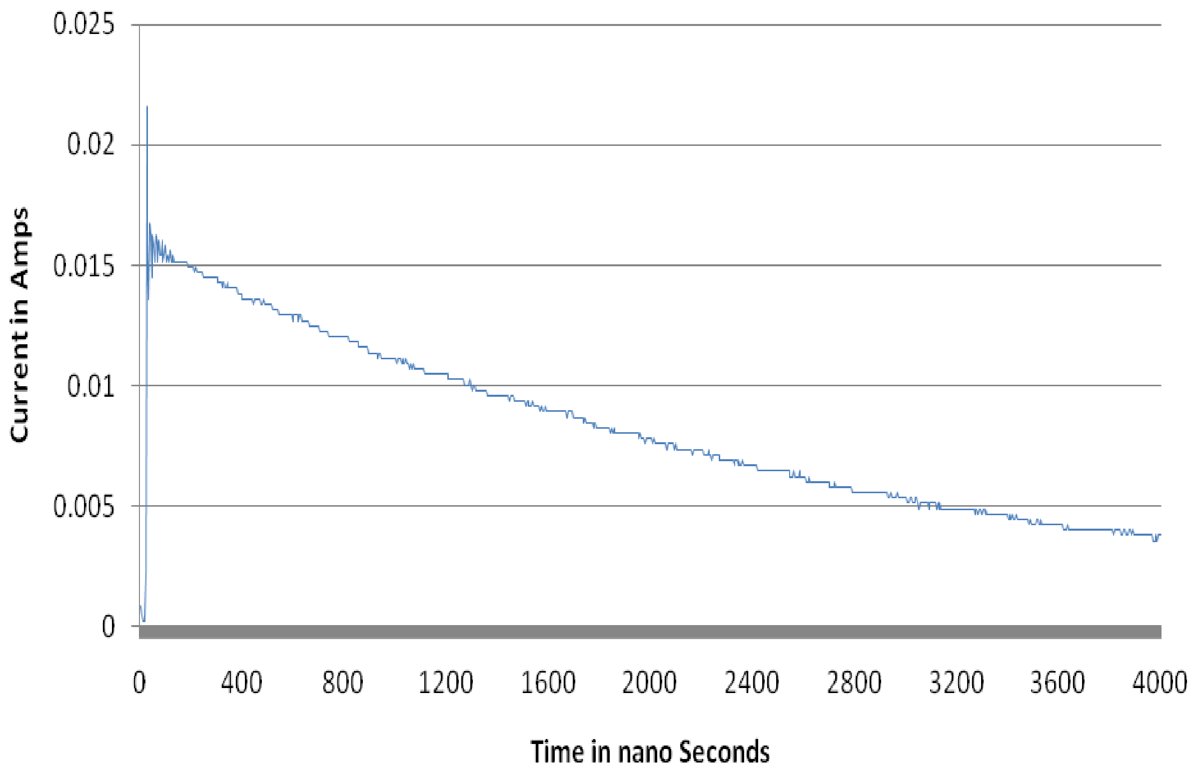

Figure 8. Plot of current of the discharge over dischager period.

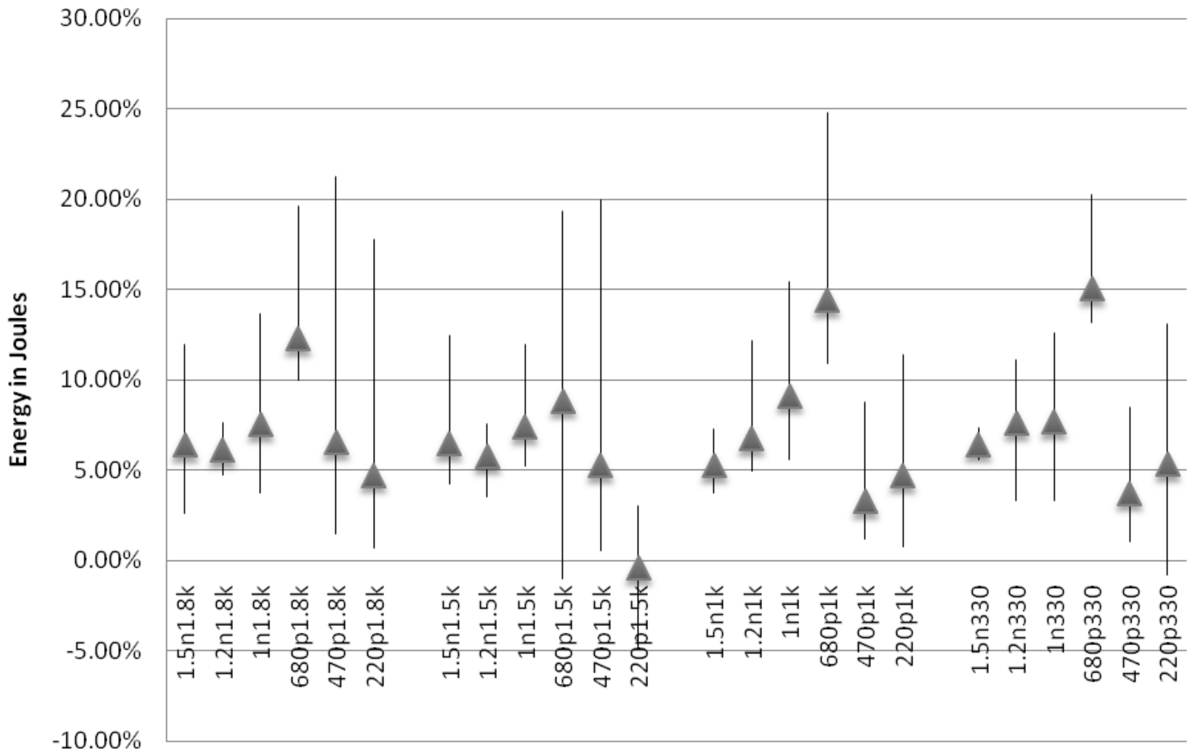

Figure 9.Plot of comparative results showing the percentage energy lost in the circuit in regard to the total capcitive energy

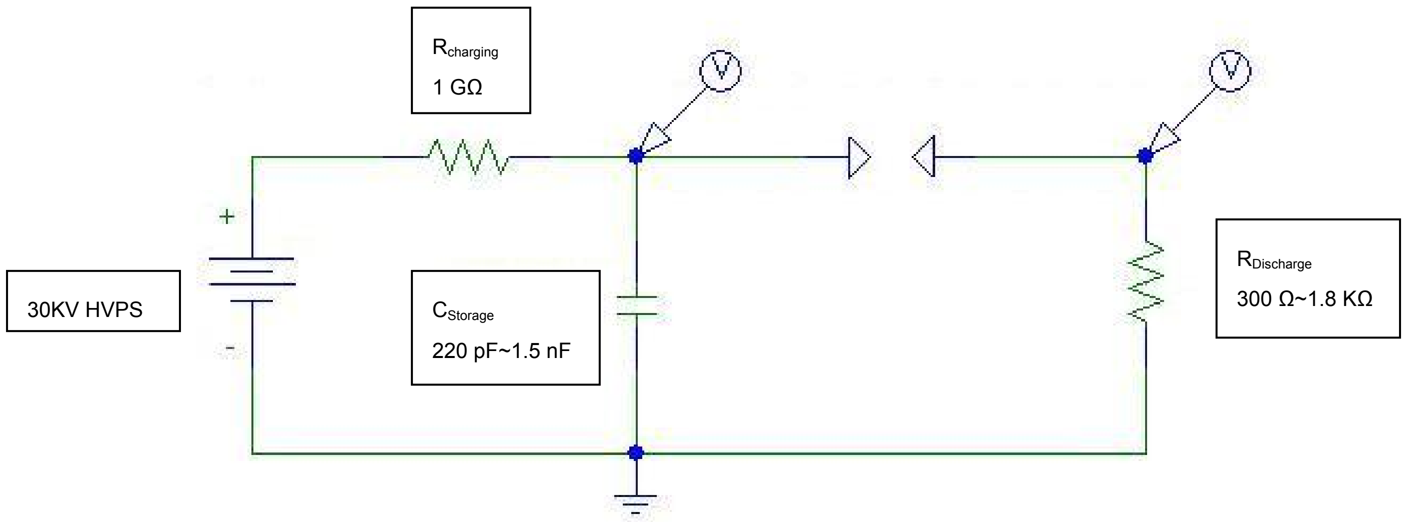

Figure 10. Schematic of the high voltage experimental circuit setup

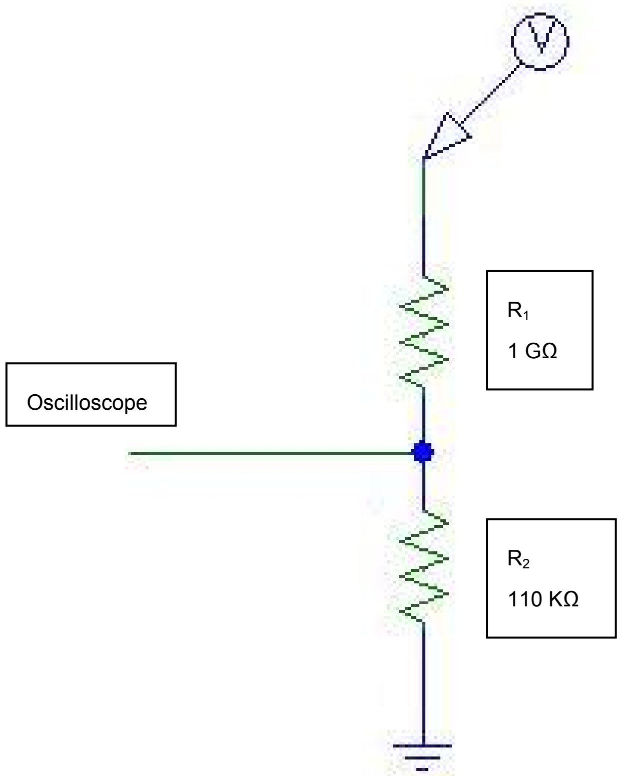

Figure 11 Schematic of the high voltage measurement voltage divider circuit

Table 1

C storage	R discharge
1.5nF	1.8kΩ
1.2nF	1.8kΩ
1nF	1.8kΩ
680pF	1.8kΩ
470pF	1.8kΩ
220pF	1.8kΩ
1.5nF	1.5kΩ
1.2nF	1.5kΩ
1nF	1.5kΩ
680pF	1.5kΩ
470pF	1.5kΩ
220pF	1.5kΩ
1.5nF	1kΩ
1.2nF	1kΩ
1nF	1kΩ
680pF	1kΩ
470pF	1kΩ
220pF	1kΩ
1.5nF	330Ω
1.2nF	330Ω
1nF	330Ω
680pF	330Ω
470pF	330Ω
220pF	330Ω

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